Micro-Stereolithography: Physics and Technologies

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REPORT DOCUMENTATION PAGE

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Outline

- Introduction
- Micro-Stereolithography (μSL)
  - μSL principles and apparatus design
  - Prototyping of polymeric and ceramic microstructures
  - Experiment and modeling
- Applications

Background

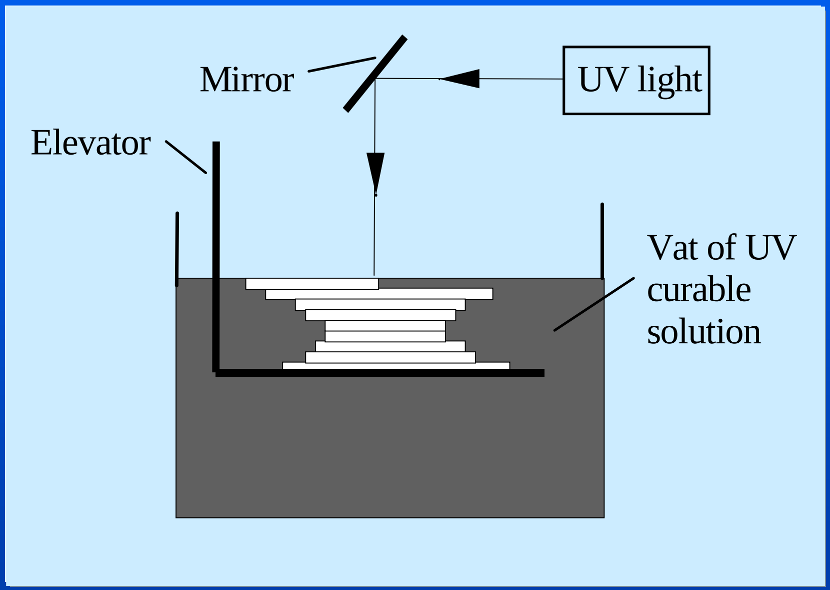
- Future high Performance MEMS requires:
  - 3D complex micro-structures
  - Incorporating with a broader spectrum of materials (Smart materials, functional polymer, and magnetic alloys)

- However, current silicon IC fabrication can not provide an effective solution.

- Other efforts:
  - X-ray LIGA: high aspect ratio 2.5D, but not true 3D
  - Micro-mechanical machining: complex 3D, but very slow and severe tool wear
  - EFAB, 3D, need many masks needed and limited to metal

A New Approach– Scale Down Rapid Prototyping Technologies

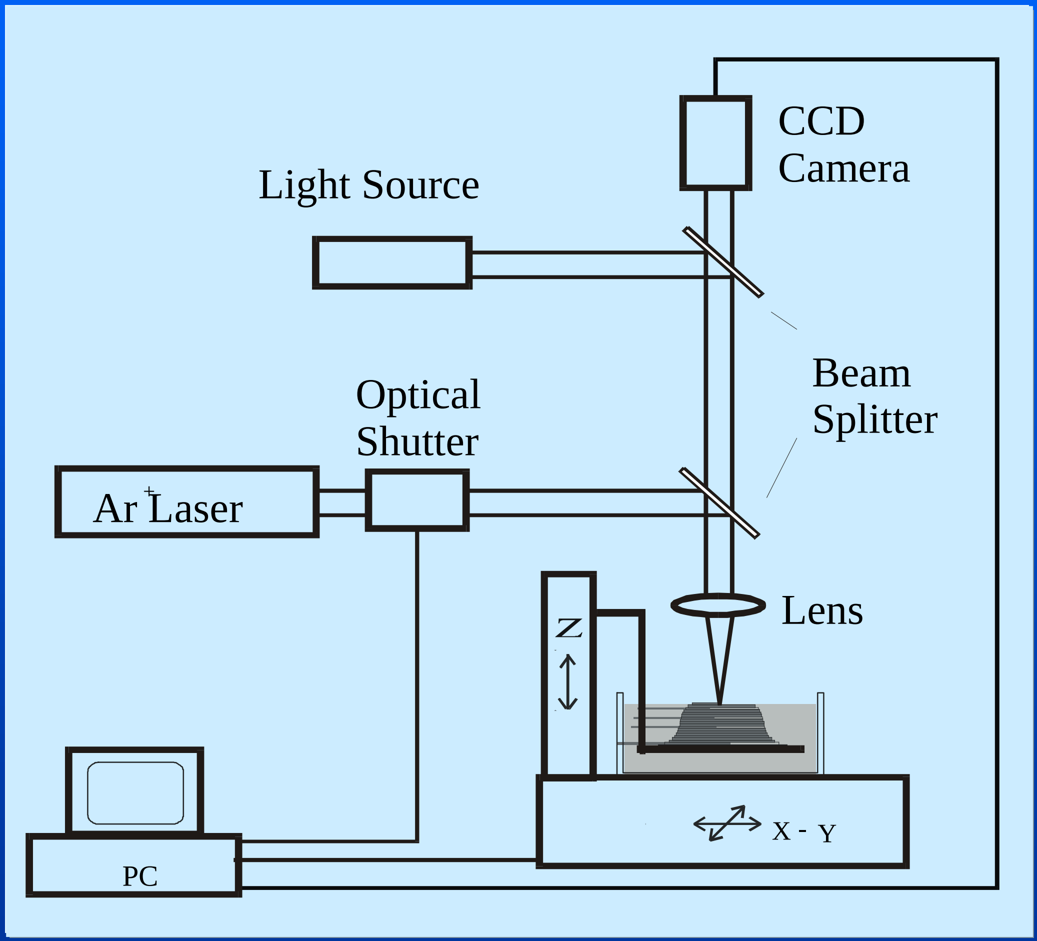
Micro-Stereolithography



(Ikuta, 1996)

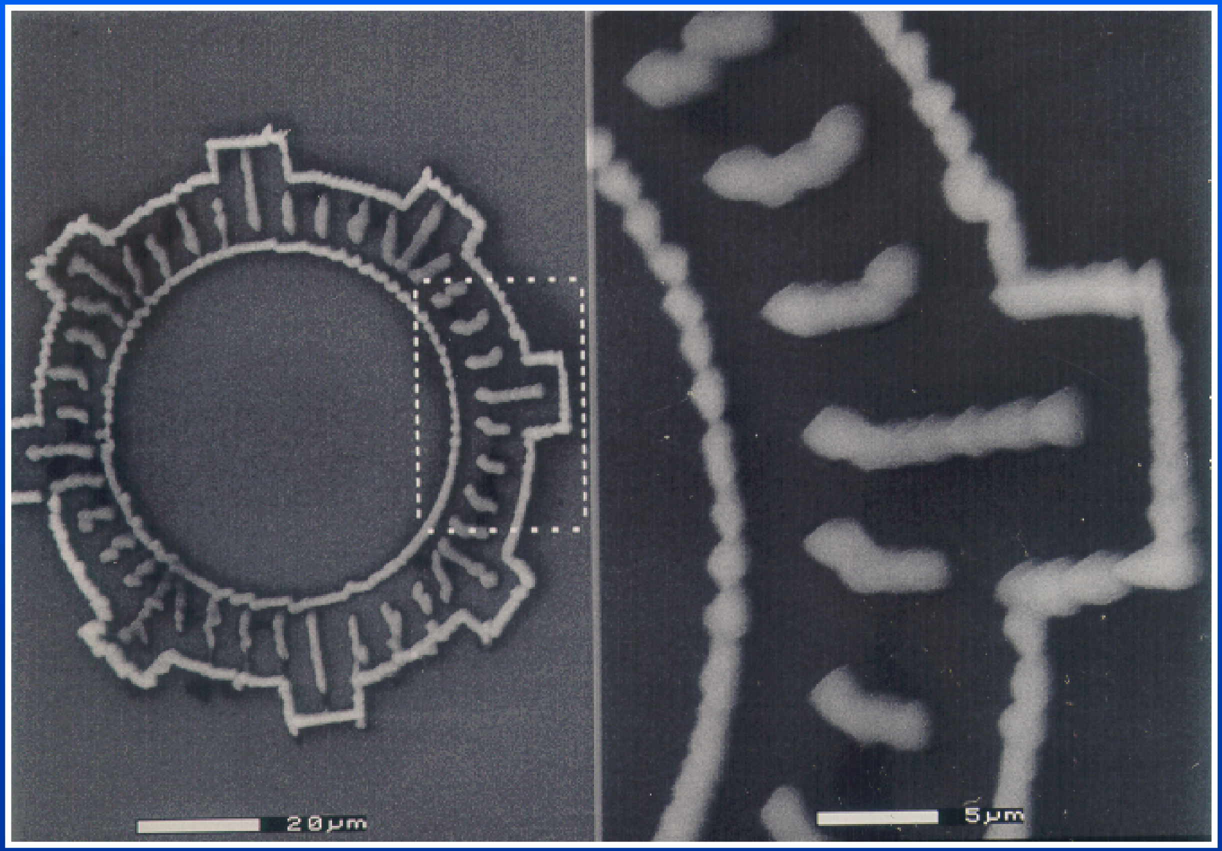
- UV laser micro photo-forming of 3D complex micro-parts
- A layer-by-layer additive process
- CAD design capability
- Incorporation of many functional materials

An Advanced Micro-Stereolithography Apparatus



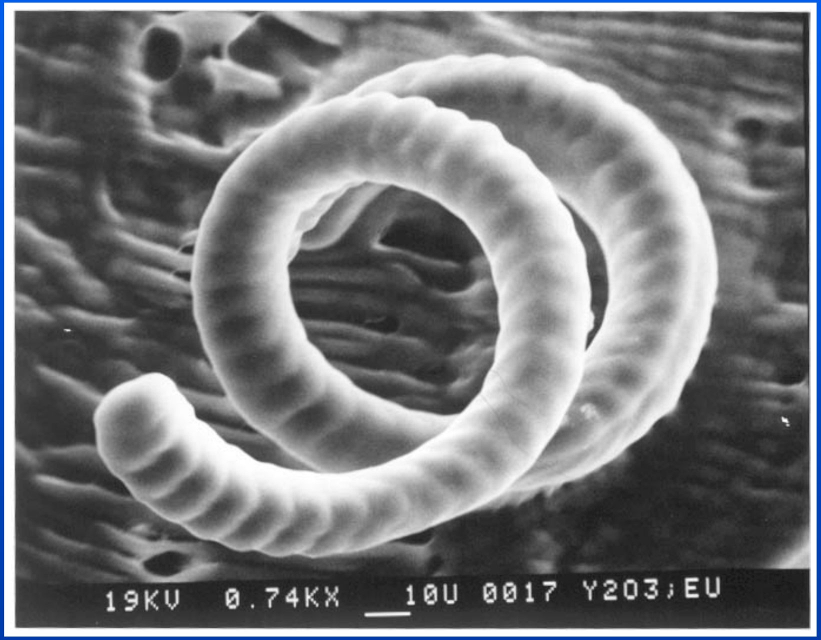
- Laser: λ=364 nm
- X-Y-Z stepper resolution: 0.5 μm
- UV beam spot: 1 μm

Test Pattern with 2 μm Line Width

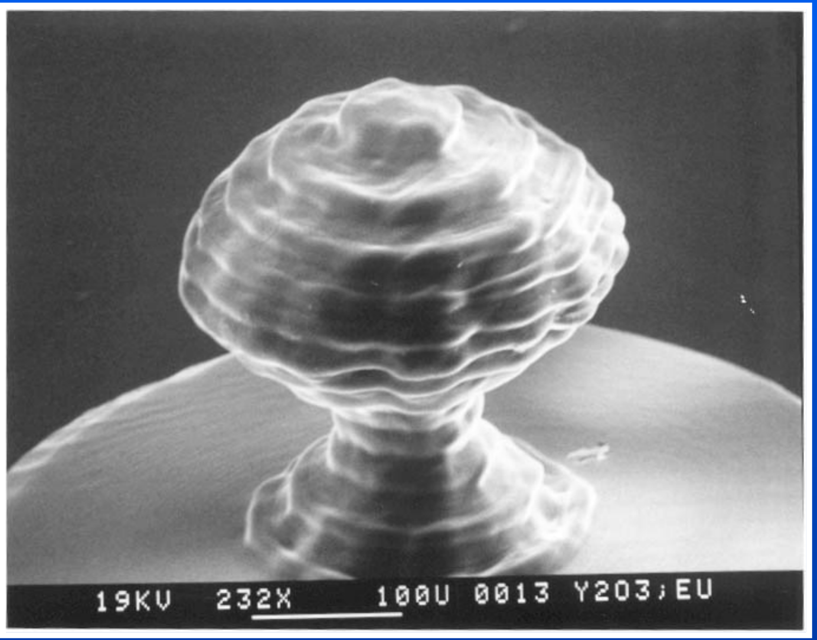


Micro-Stereolithography of 3D Complex Structures

- Micro-spring

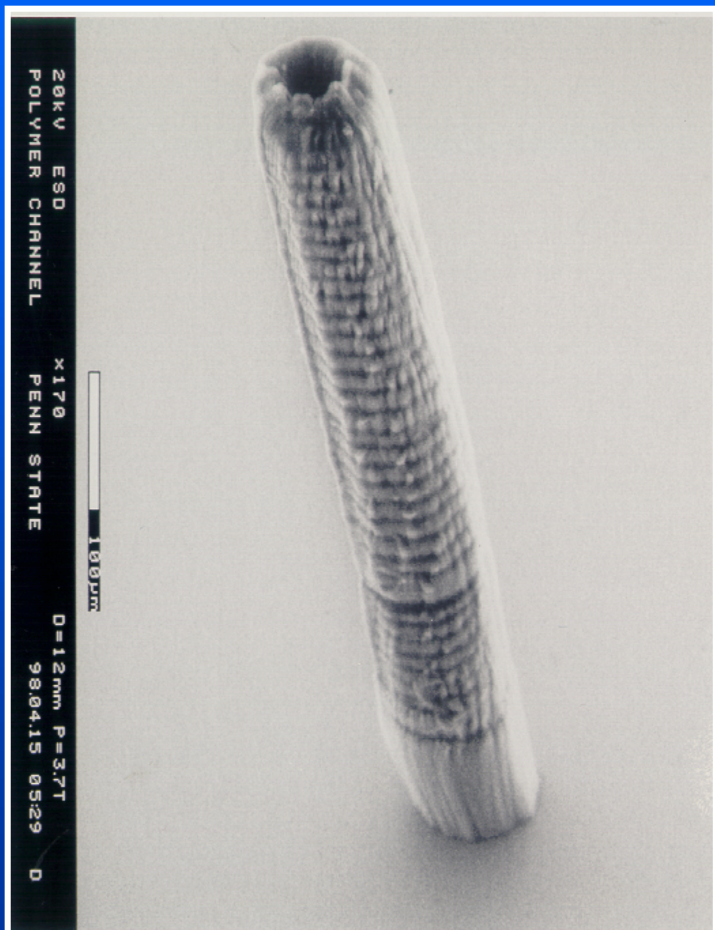


- Micro-mushroom



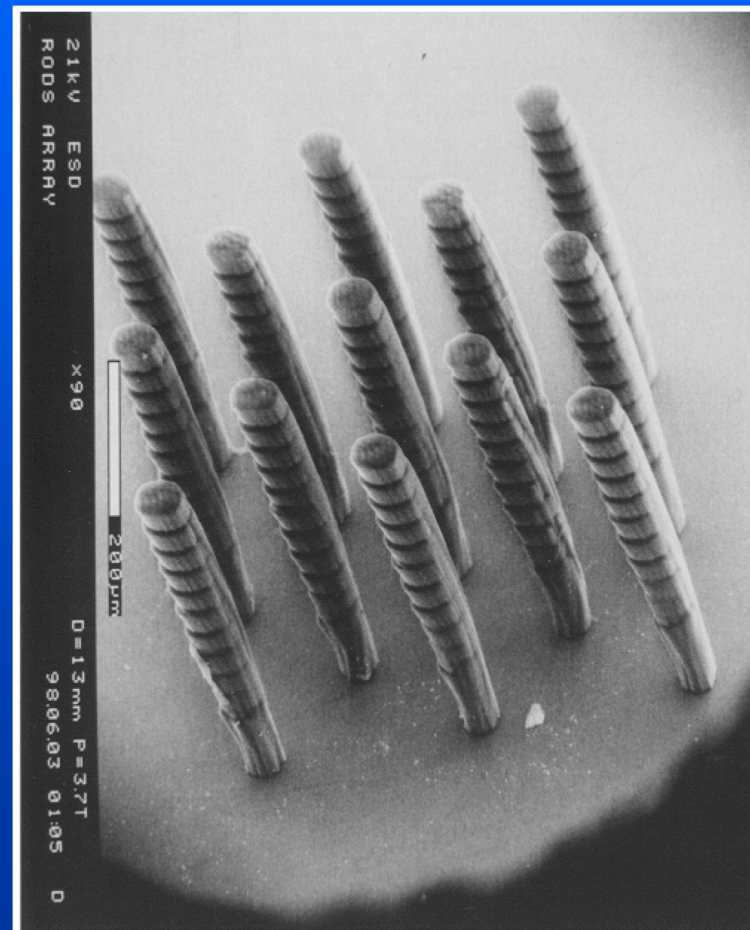
- **Micro-tube**

(50 μm inner diameter and 800 μm long)



- **Micro-rod Array**

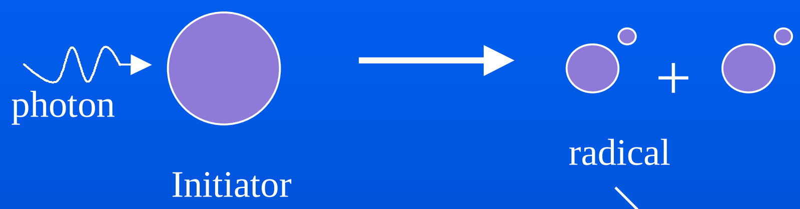
(50 μm diameter and 500 μm long)



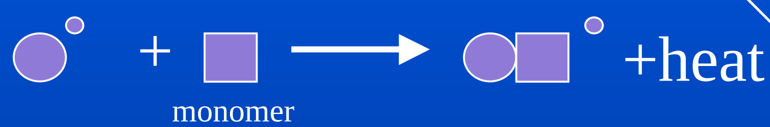
Simulation of Micro-Stereolithography of Polymer

Photopolymerization

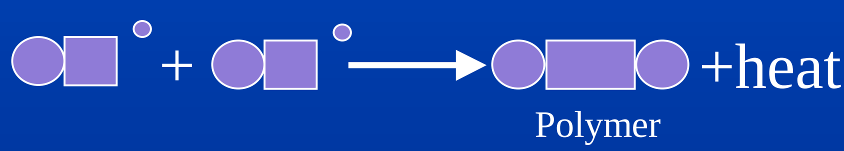
- **Initiation:**

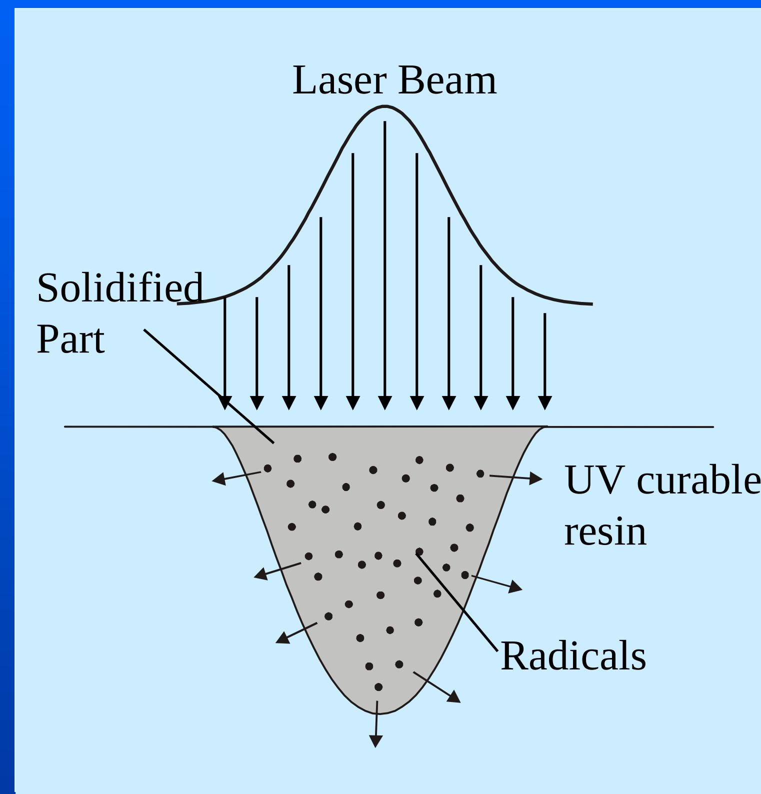


- **Propagation:**



- **Termination:**





Simulation Approach

- **Light absorption:**

$$\frac{dI}{dz} = -\varepsilon[S]I$$

- **Photoinitiation:**

$$\frac{d[S]}{dt} = -\psi\varepsilon[S]I$$

- **Diffusion of Radicals:**

$$\frac{d[R]}{dt} = D[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial[R]}{\partial r}) + \frac{\partial^2[R]}{\partial z^2}) + \phi\varepsilon[S]I - k_t[R]^2$$

- **Polymerization Kinetics:**

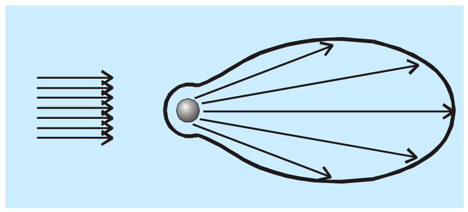
$$\frac{d[M]}{dt} = -k_p[R][M]$$

- **Heat Transfer:**

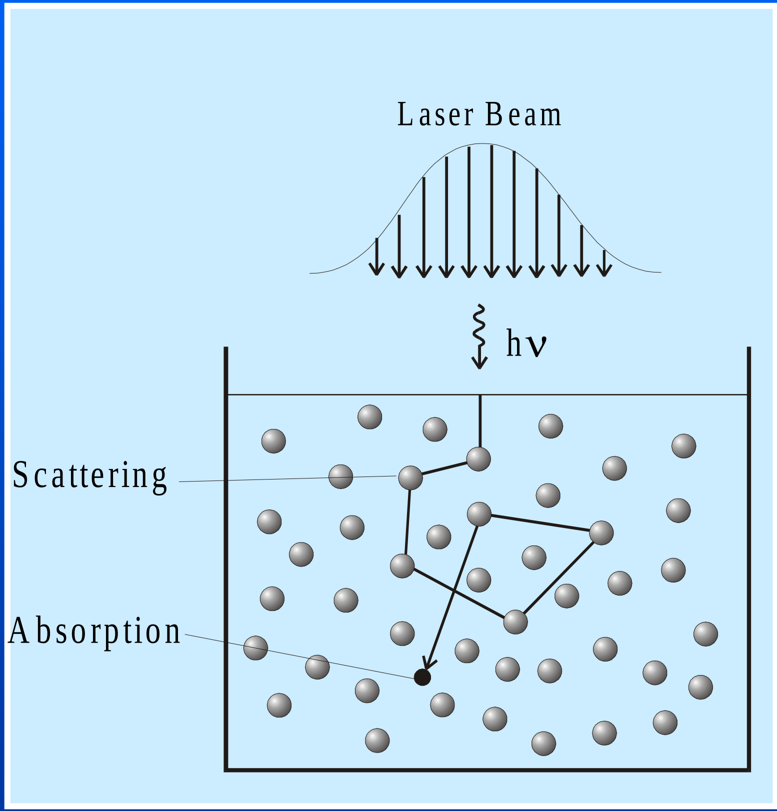
$$\rho C_p\frac{\partial T}{\partial t} = k[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial T}{\partial r}) + \frac{\partial^2 T}{\partial z^2}] - k_p[R][M]\Delta H$$

Monte-Carlo Simulation of μSL of Ceramics

Single photon tracing processes

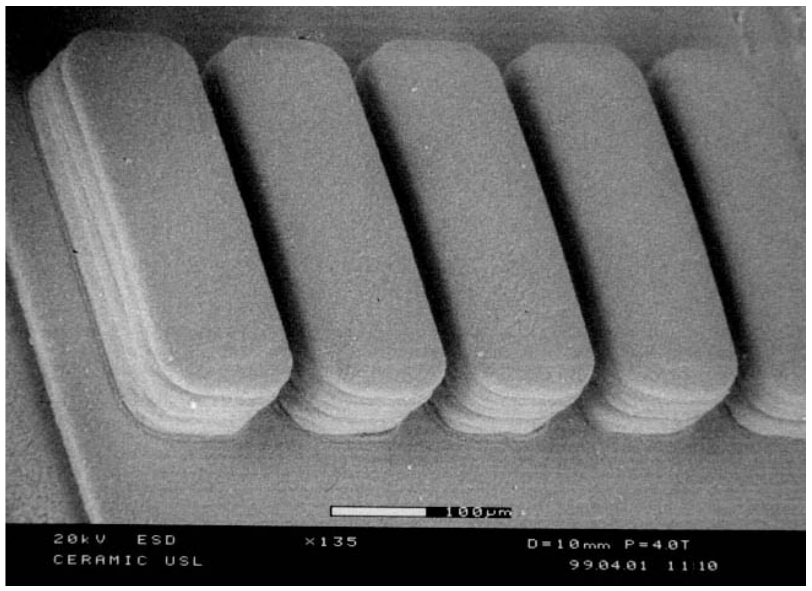


- Scattering
  - Mie theory
- Absorption during traveling
  - travel: $P = e^{-l/\lambda}, \lambda = \frac{4 \cdot r}{3 \cdot s} (MFP)$
  - absorption: $P_a = e^{-\varepsilon \cdot l}$
- Photo polymerization

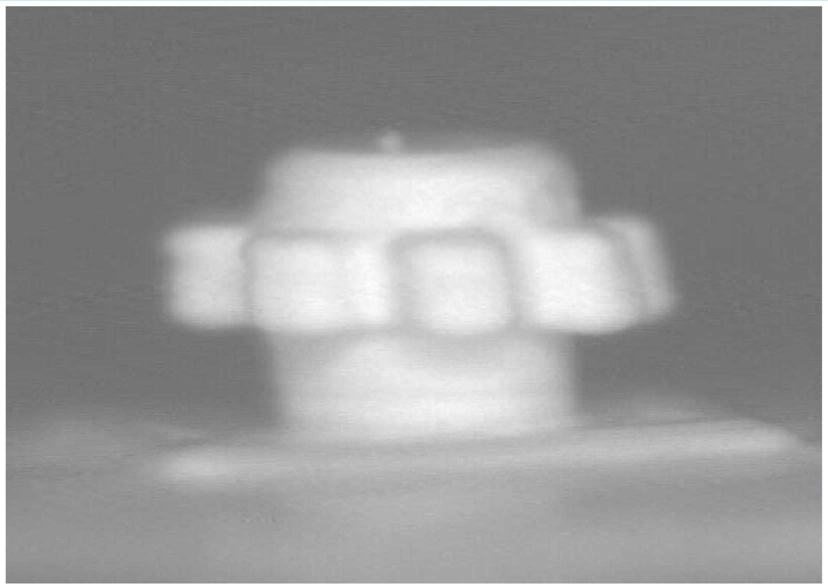


3D Ceramic μSL

30 μm Alumina Micro Channels

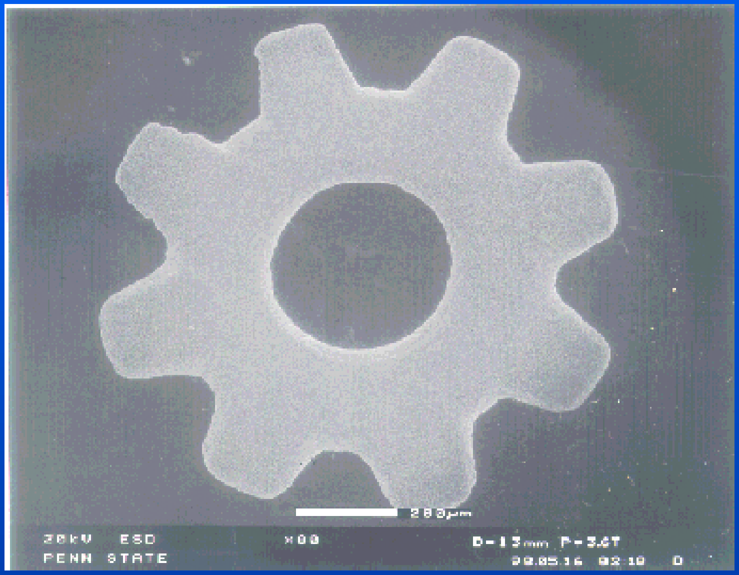


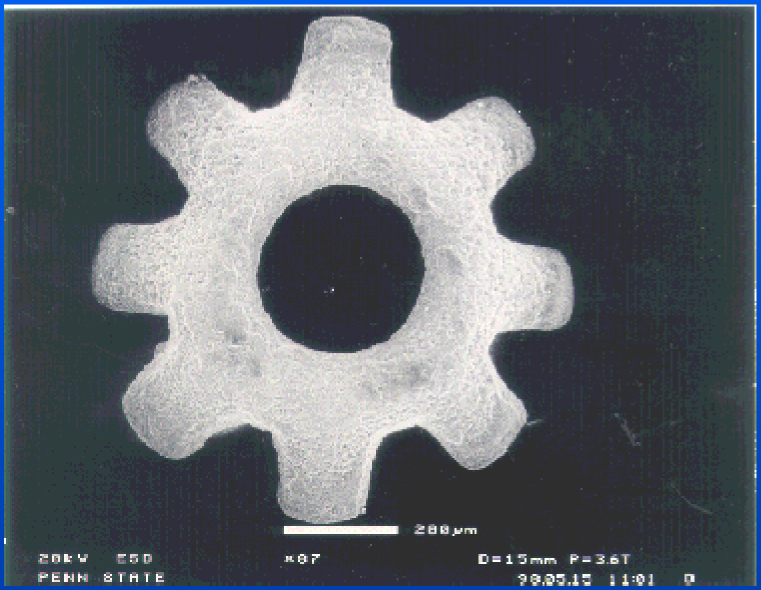
400 μm Alumina Micro Gear



Micro-Stereolithography of Ceramic Structures

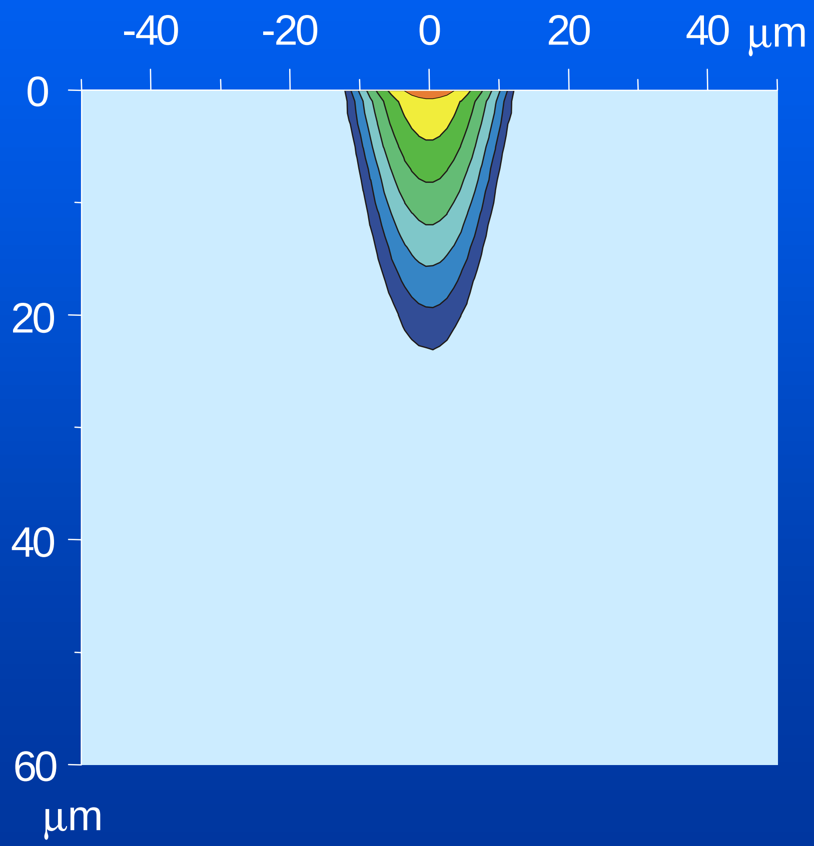
- Green Alumina Gear
- Sintered Alumina Gear



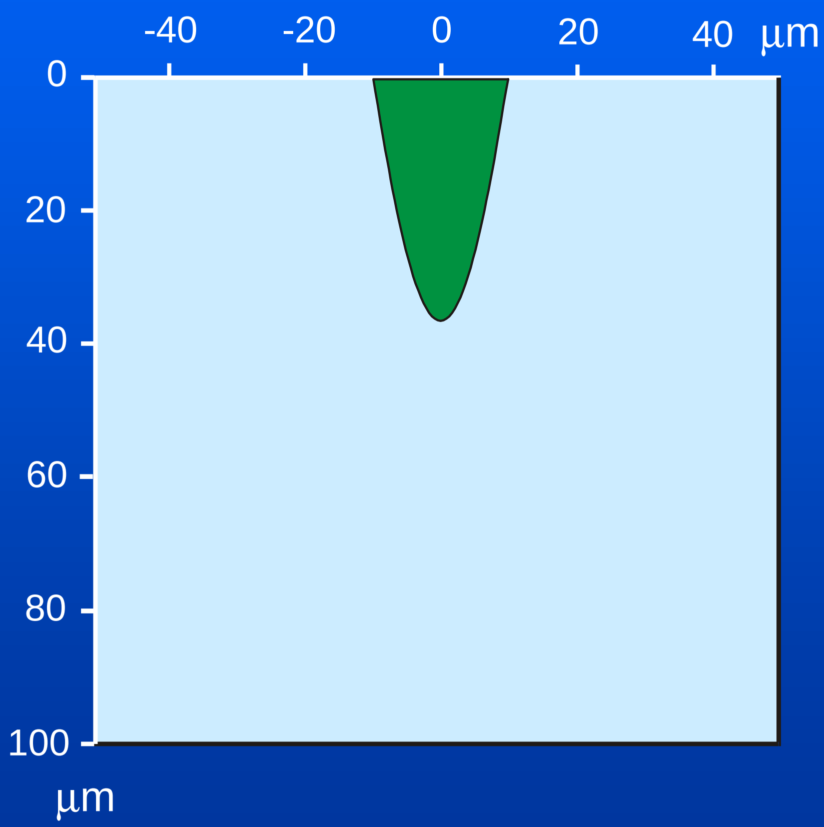


Sintered at 1400 °C and 3 hours
Shrinkage due to sintering: 5-16%

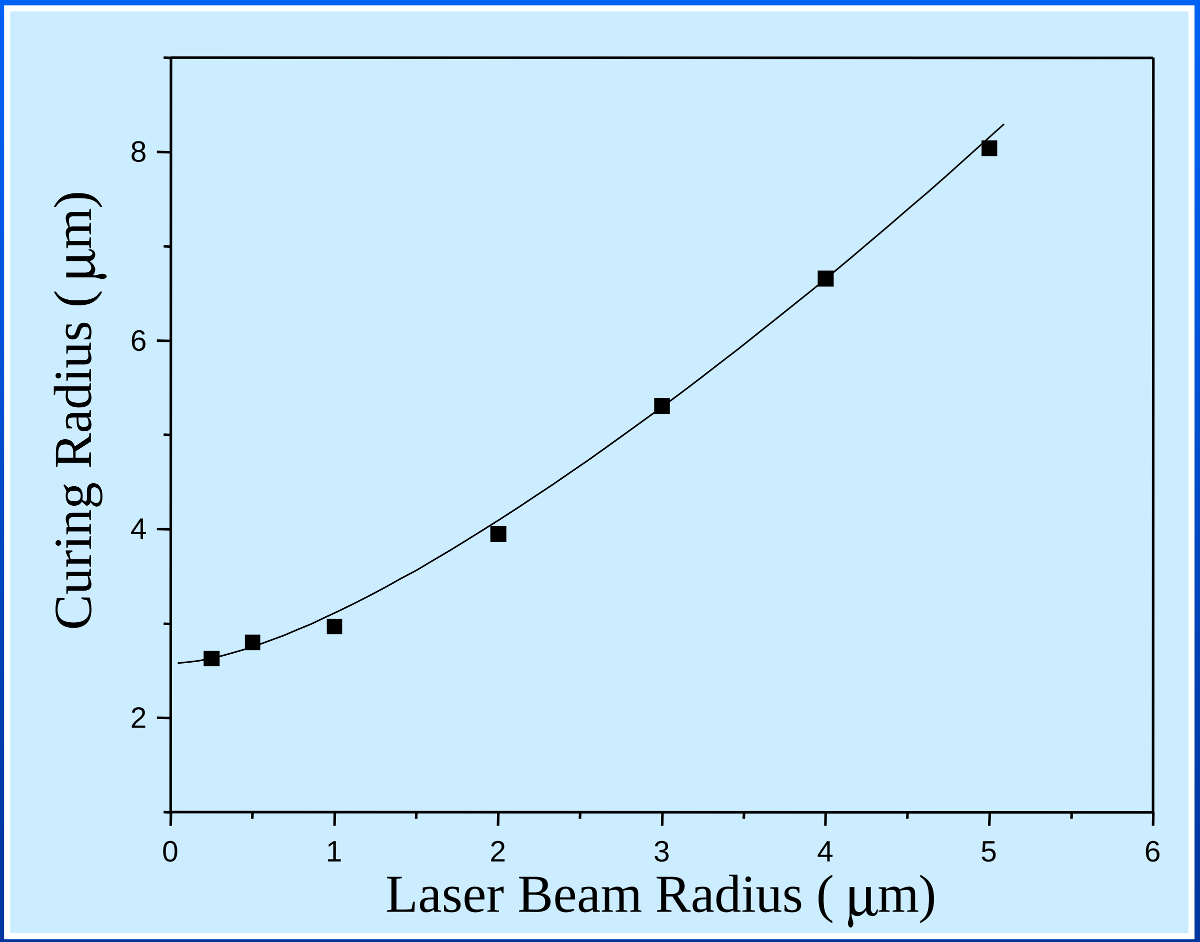
Light Scattering



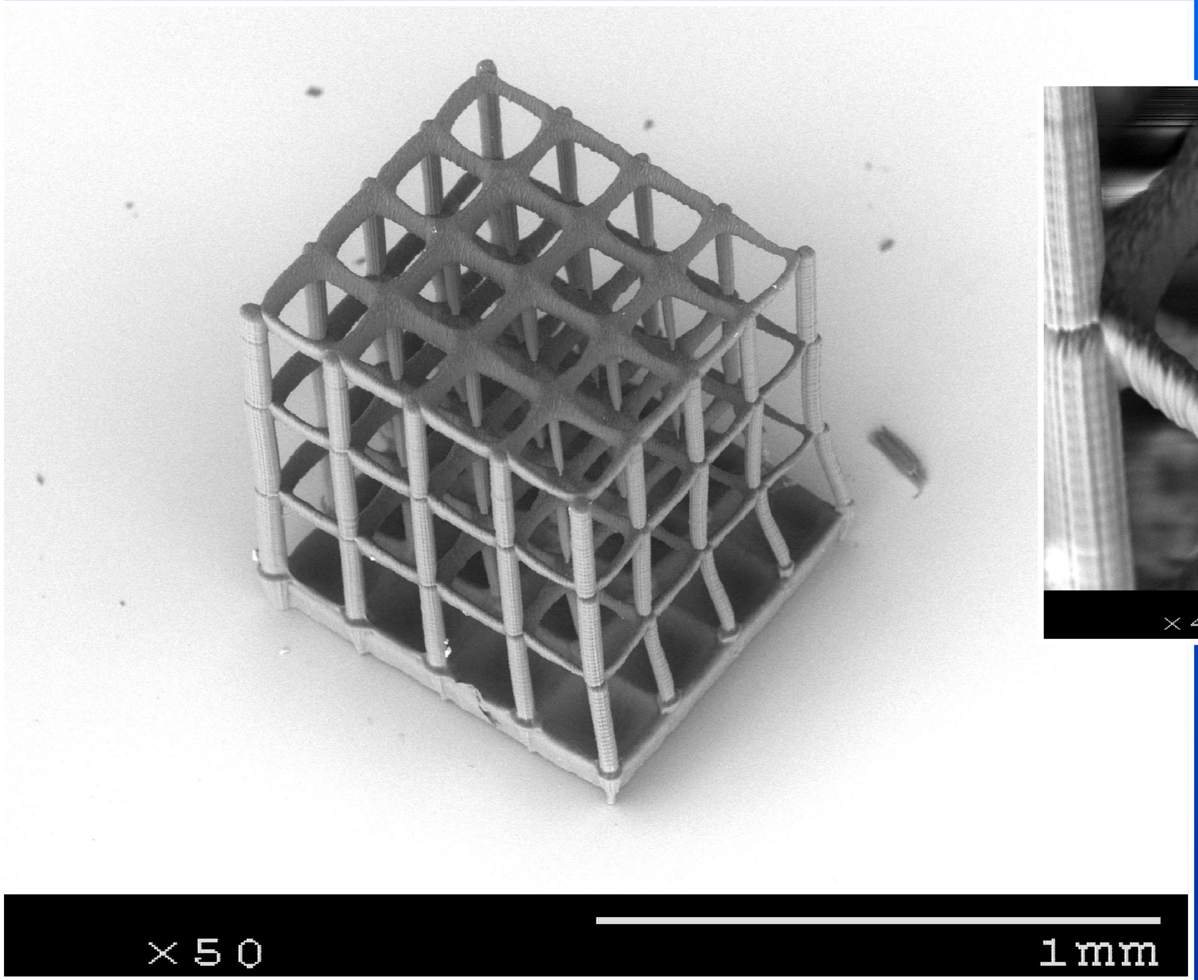
Polymerization

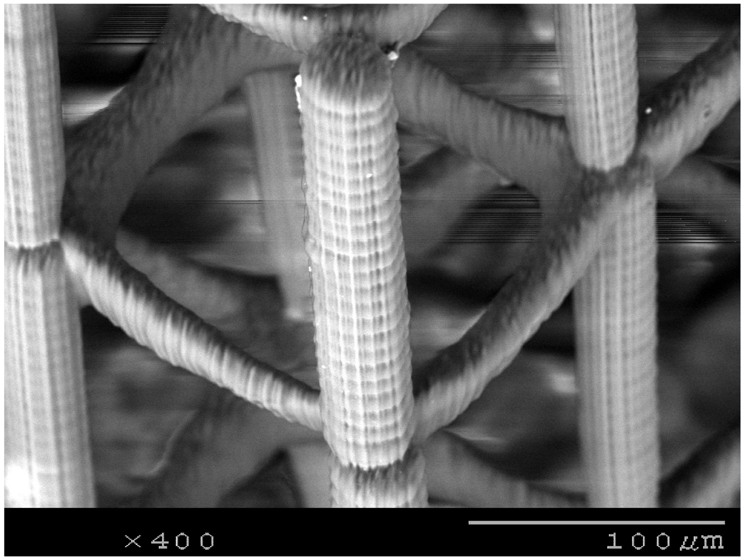


Lateral Resolution Limit in μSL of Ceramics

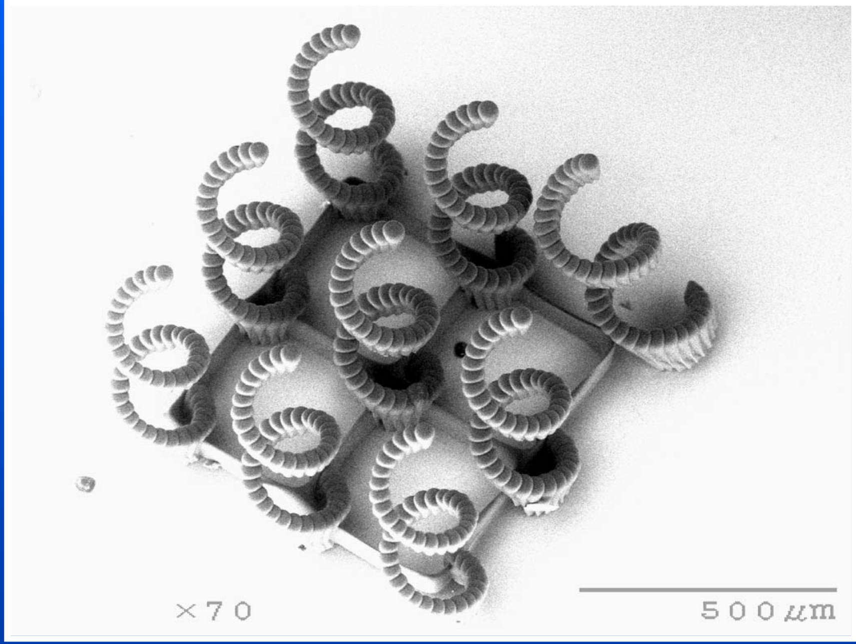


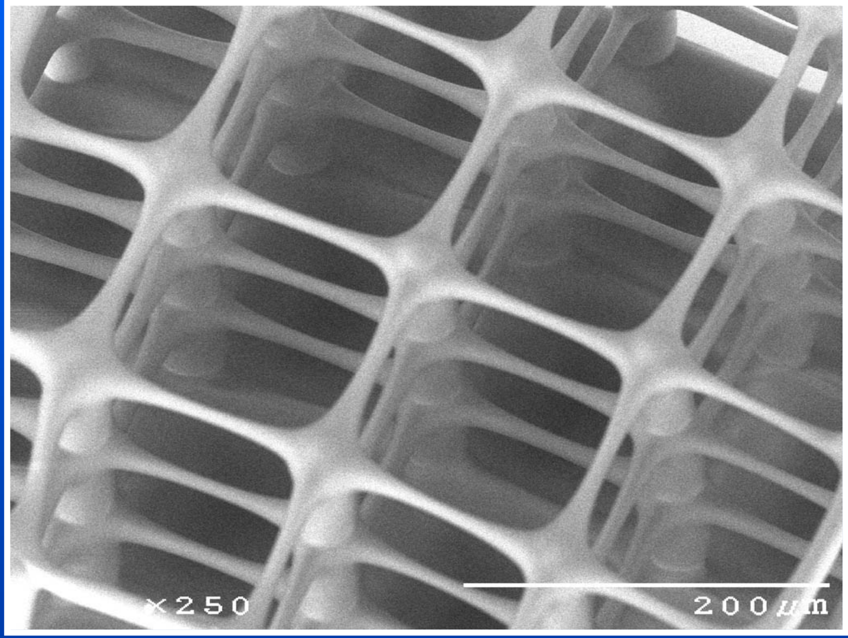
3D Matrix by DMD-μSL

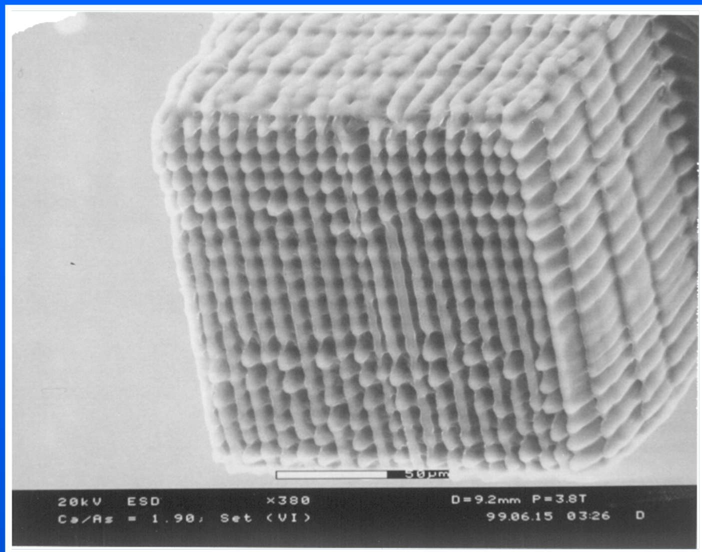




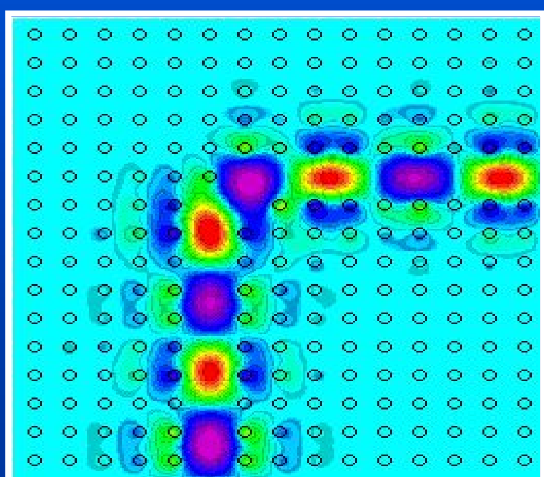
3D Coils Array and Micro-Matrix







(Zhang, 1999)



(Joannopoulos, 1996)

3D Photonic Band-gap Crystals

- Transmit/forbid light beam of selected wavelength (12 dB)

- Defects are pre-designed by CAD and embedded into the PBG by micro-stereo-lithography (decide what type defects and where they localed, which is impossible in atomic scale defects in semiconductor)

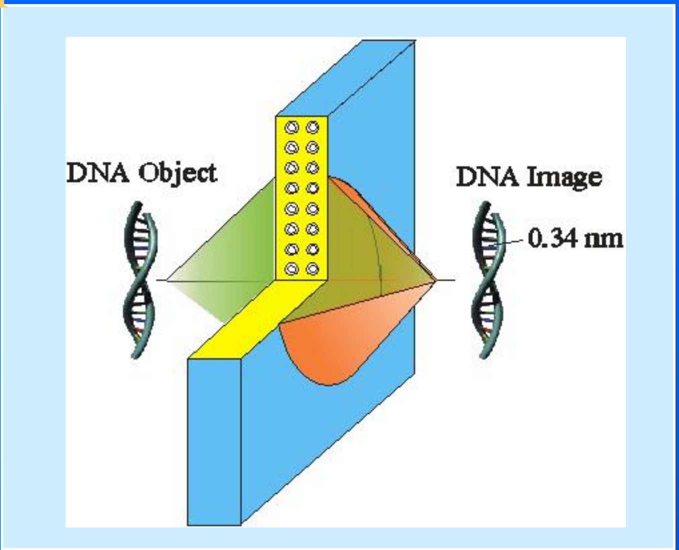
Applications

- Loss-free optical fiber
- High efficiency visible –IR bandpass filter/waveguide
- Resonant cavity in solid state laser

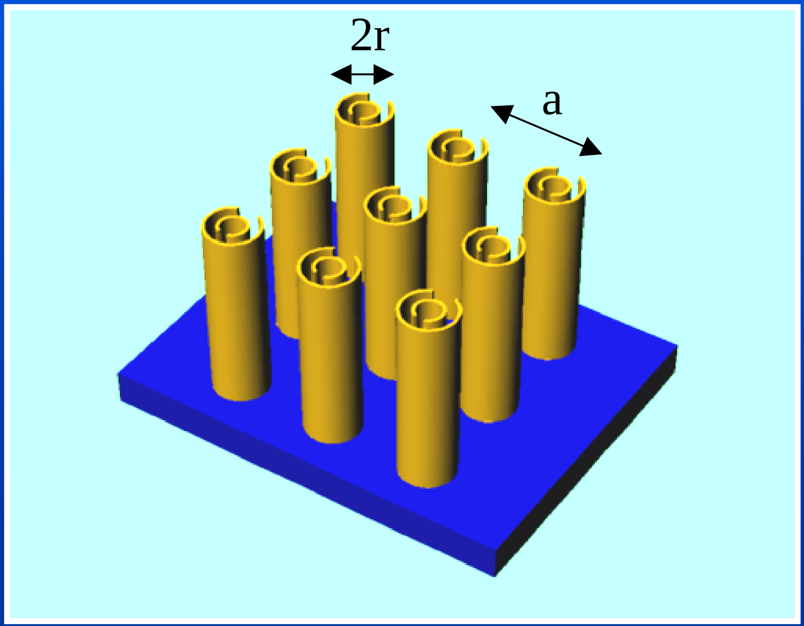
Artificial Materials With Unprecedented Properties

(Theoretical work of John Pendry, 2000)

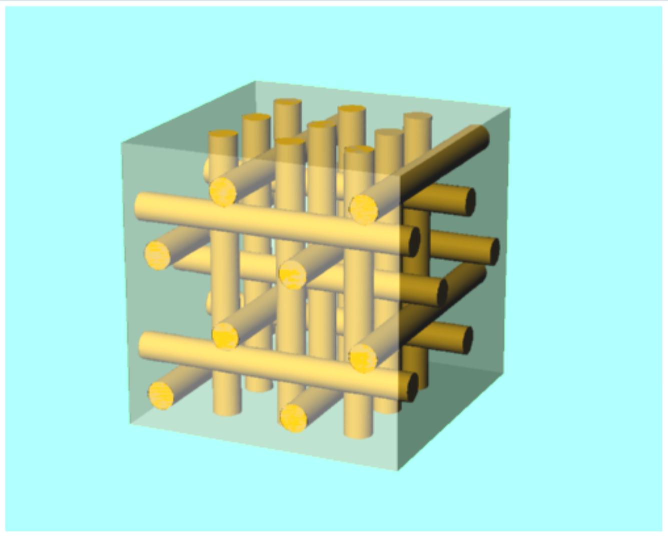
Super-lens



Artificial Magnetism at High *f*

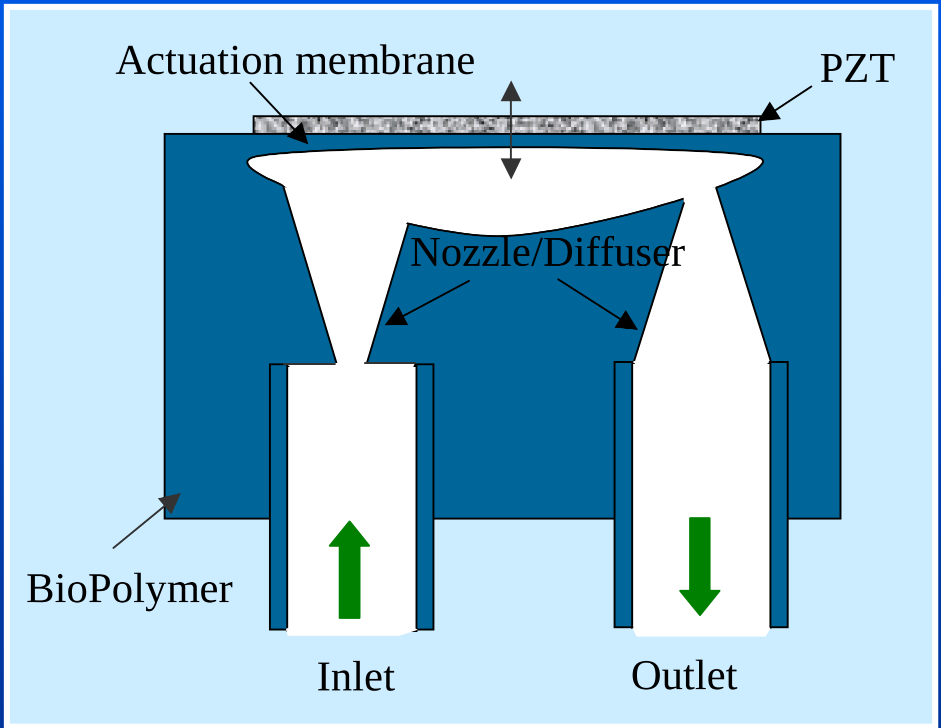


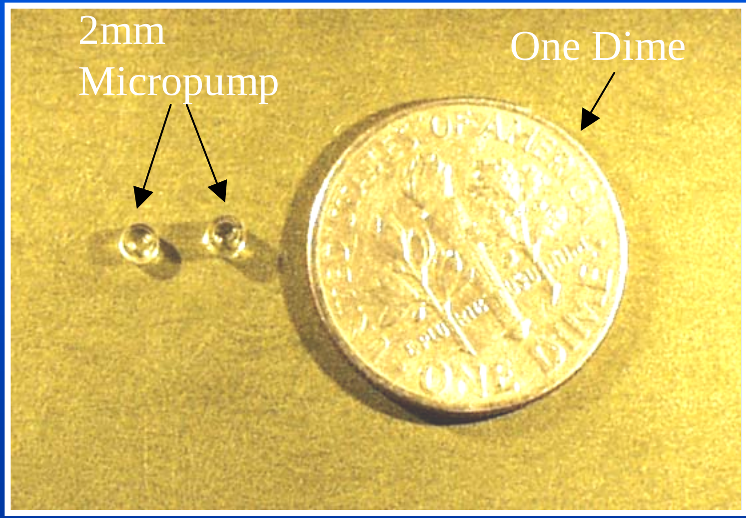
Artificial Plasma



3D Valveless Micropump

- Truly 3D cavity structure to optimize the design
- High reliability due to no movable valves
- A wide variety of materials (eg. Bio-polymer)





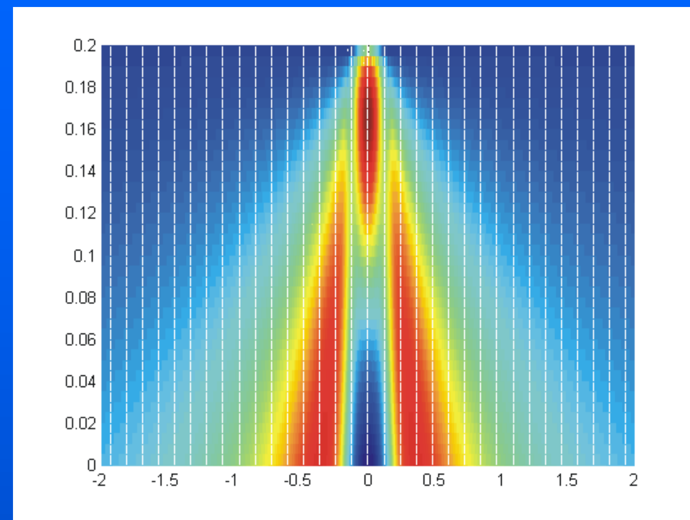
Near Field Optical nanolithography(NSOL)

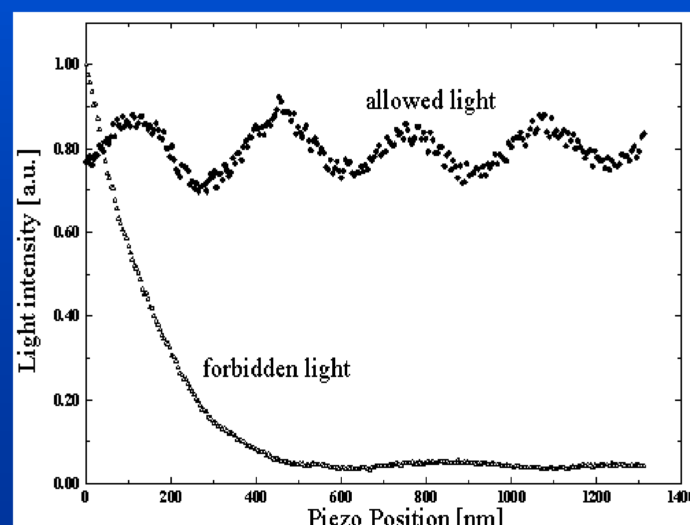
- Near field scanning optical microscopy (NSOM)- a proven technology to break the diffraction limit.

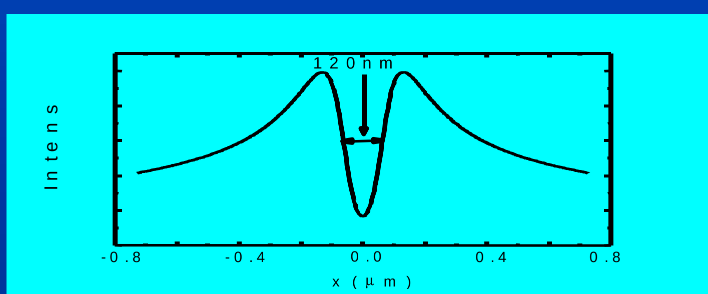
- 2D nanopatterning with NSOM demonstrated features with ~100nm lateral resolution

- Computer simulation propose that NSOM has the potential in 3D nanolithography

-







Conclusions

- Scanning micro-stereolithography has been developed
- Micro-stereolithography of complex 3D micro-structures has been demonstrated; For the first time, μSL of ceramic micro-structures has been succeeded
- Theoretical Simulation of micro-stereolithography shows good agreements with preliminary experimental results
- The unique 3D techniques enable exciting applications in photonics, bioMEMS and possibly novel thermally engineered materials.